Gravitational Waves from Compact Objects Accreting onto AGN

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Acknowledgements

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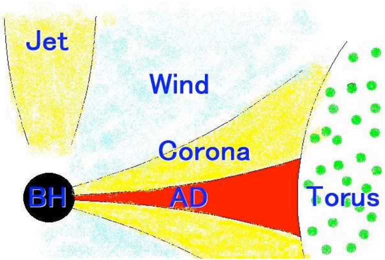
Outline

- Astrophysical background and motivation
- Results
    - Description of model
    - Types of GW sources
    - Dependence on model parameters
    - Resolvability and Subtractability
- Applications/Implications for LISA

AGN emit EM radiation at all wavelengths

- For SMBH masses of $M \sim 10^6 - 10^9 M_\odot$, typical accretion disks can extend many parsecs and have masses comparable to M
- EM spectra should be dominated by IR-UV wavelengths, with non-thermal radio and X-ray emission from the jet and corona
- The outermost region of the disk is thought to be a torus of molecular gas

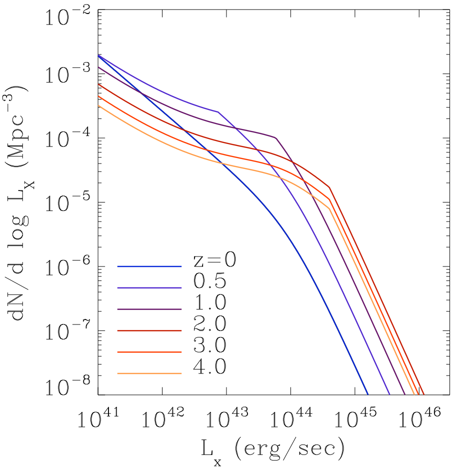


credit: J. Fukue

Star formation in the outer disk

- The outer regions of the disk/torus will be dominated by gas pressure and should be self-gravitating Shlosman & Begelman 1987
- Above the Toomre limit ($\Sigma \gtrsim \frac{c_s \Omega}{\pi G}$; Toomre 1964) the disk will be gravitationally unstable to collapse
- This may result in a complete fragmentation of the disk into massive stars Levin 2003, 2006
- Or isolated super-massive stars may form and subsequently clear gaps in the disk via gas accretion Goodman & Tan 2004
- The disk-embedded stars will then evolve to compact objects (COs) on the accretion time-scale as they migrate through the disk and eventually merge with the SMBH via gravitational radiation

AGN activity can act as a tracer for inspiral events

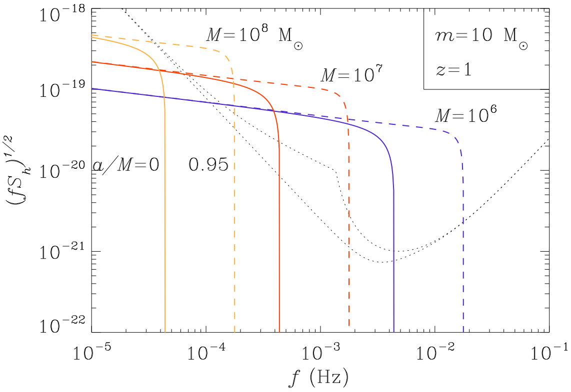


Ueda et al. 2003

- $L_X = f_X f_{\rm Edd} L_{\rm Edd}(M)$
- The hard X-ray luminosity function is relatively well-determined out to $z \sim 3-4$
- X-rays suffer less extinction than IR/visible emission
- Provide good estimate of *intrinsic* luminosity

Each inspiral event is adiabatic and circular

The GW spectrum is characterized by a cut-off frequency determined by the mass and spin of the SMBH.



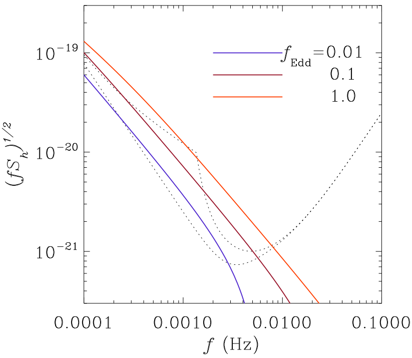
cf. Finn & Thorne 2000

Model Parameters

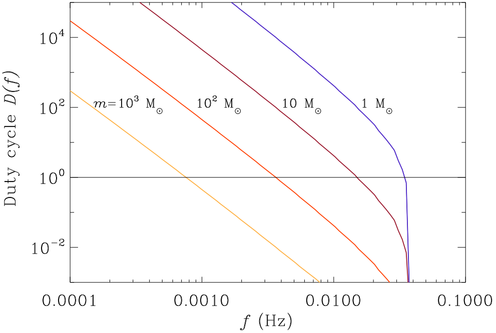
$$\frac{d\rho_{\rm gw}(f)}{d\ln f} = \frac{\eta_{\rm gw} f_{\rm co}}{\eta_{\rm em} f_X} \int \left|\frac{dt}{dz}\right| \frac{dz}{1+z} \int_{L_{\rm min}}^{L_{\rm max}} dL_X \frac{dN(L_X)}{d\ln L_X} \frac{1}{E_{\rm gw}} \frac{dE_{\rm gw}}{d\ln f} [f_z(M)]$$

parameter	min	max	preferred	description
$f_{\rm co}$	0	1	0.01	fraction of accreted mass in COs
f_X	0	1	0.03	fraction of EM radiation in X-rays
$f_{\rm Edd}$	0	$\gtrsim 1$	0.1	fraction of Eddington luminosity/accretion rate
$\eta_{\rm em}$	0	0.4	0.2	efficiency of converting gas to EM radiation
$\eta_{\rm gw}$	0	0.4	0.2	efficiency of converting COs to GW radiation

The time-averaged GW signal is comparable to the LISA noise curve



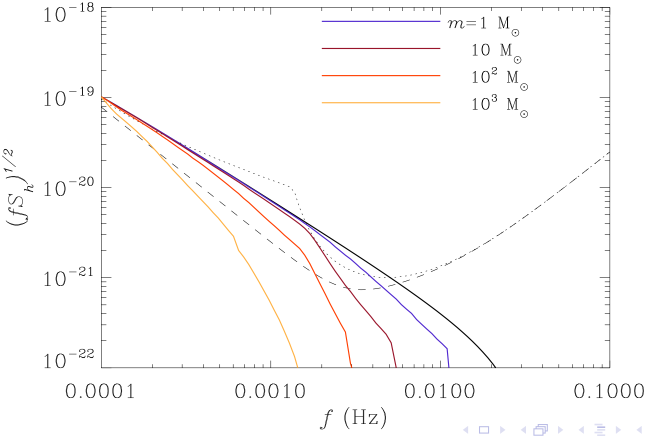
Stochastic vs. chirp signals



- The duty cycle is an estimate of the number of sources around each frequency at any time
- When $D(f) \gtrsim 1$, the sources may be treated as stochastic
- Above a certain frequency, the GW signal will be more like an isolated chirp

We can subtract the chirp signals with large SNR

For a given M, m, distance, and SNR threshold, we calculate a cut-off frequency above which the inspiral signal can be subtracted, leaving behind an unresolvable stochastic background



Astrophysical considerations/caveats

- We have relatively little data on the low-luminosity and low-mass end of the distribution function
- Accretion and stellar evolution time scales may compete: main sequence stars would likely be tidally disrupted before merger
- Still very large uncertainty in $f_{\rm co}$ and m
- Greater understanding will require detailed simulations of outer disk
- f_X and $f_{\rm Edd}$ most likely are functions of M and also evolve in time: "anti-hierarchical" evolution Marconi et al. 2004; Merloni 2004

Applications/Implications

- Event rates should be comparable to other stochastic EMRI signals, e.g. WD, NS captures Barack & Cutler 2004

Stochastic regime ($f \lesssim 1$ mHz):

- LISA should be able to put interesting limits on a number of model parameters, in particular $f_{\rm co}/f_{\rm X}$
- If the stochastic background is high enough, it still may be subtractable; not like WD background

Chirp regime ($f \gtrsim 1$ mHz):

- Individual events should be resolvable as EMRIs: can be used to measure SMBH spin and possibly test GR
- Could be new source of IMBH-SMBH binaries, with *clear EM counterpart* cf. Milosavljevic & Phinney 2005
- Should have high SNR even at large redshifts; individual events can be detected and subtracted